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THE USE OF SIMULATION IN MILITARY TRAINING: VALUE, INVESTMENT, AND POTENTIAL

Henry Simpson
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DEFENSE MANPOWER DATA CENTER
Training & Readiness Evaluation and Analysis Division

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13. ABSTRACT (*Maximum 200 words*)
A study was conducted to assess capabilities and limitations of simulation for military training; DoD investments, plans, and programs for simulation; and cost-saving potential. Findings were (1) simulation technology is advancing, but faces a number of technical challenges; (2) the Services accept and use live, stand-alone single-system, and constructive simulations, and are making increasing use of virtual simulation; (3) cost data on simulation are not reported regularly or consistently but approximate relative levels of investment can be estimated; and (4) the Services have a multitude of simulation programs, with much of their planned technology development work is in the areas of virtual simulation and range instrumentation.

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PREFACE

The Committee on Armed Services of the House of Representatives, 103rd Congress, directed the Secretary of Defense to prepare a report on the value of simulation and the potential training efficiency from increased use of simulation. In responding to the Committee's request, the Defense Manpower Data Center and the Office of the Under Secretary of Defense for Personnel and Readiness reviewed several recent analyses relating to simulation and prepared the report to Congress. Because of space limitations, much of the information generated by the analyses had to be omitted from the Congressional report. This report captures the information presented in the Congressional report as well as background, analyses, and other information necessary to provide a more complete picture of simulation as it relates to military training in the Department of Defense.

This report shows that the Department has a great deal of experience with modeling and simulation and is leveraging the potential of the technology. It is using the technology to train military personnel more efficiently and effectively. Evidence suggests that the next generation of simulations will improve training and increase savings, simultaneously providing the capability to develop doctrine and tactics, assess war-fighting situations, define operational requirements, and assist the acquisition process. To achieve the full potential of simulation, the Department must monitor and manage simulation programs in a number of different areas--to increase the visibility of resources, improve the focus of evaluations, ensure that Service investments are balanced and complementary, and increase coordination across Services and Defense agencies.

The authors are indebted to Jesse Orlansky of the Institute for Defense Analyses for his generous help in providing information and suggestions for the preparation of this report. Donald Johnson of the office of the Deputy Under Secretary of Defense for Readiness provided valuable data and critiques of early versions of the report. Several members of the Defense Manpower Data Center staff contributed source data and analyses to this report; particular thanks go to LTC Dean Craig, Walter Davis, Yvonne Delp, Donna Keeley, and Vincent Lauter.

EXECUTIVE SUMMARY

Tasking

The Committee on Armed Services of the House of Representatives, 103rd Congress, directed the Secretary of Defense to prepare a report on the value of simulation and the potential training efficiency from increased use of simulation. In its tasking, the Committee expressed the belief that declining training resources made it important to optimize training and to increase skill proficiencies more effectively and efficiently. The Department of Defense (DoD) was directed to quantify the impact of simulation technology on military training to determine whether (1) level of investment is appropriate and (2) significant savings are possible.

Objectives

The objectives of the study were as follows:

- Determine current capabilities and limitations of simulation for training
- Quantify the impact (value) of simulation technology on military training
- Determine the DoD's level of investment in training-related simulation
- Determine DoD and Service plans and programs for simulation
- Determine whether cost savings are possible through increased use of simulation

Method

This report is based on several recent analyses performed by the Institute for Defense Analyses, the Defense Manpower Data Center, the Defense Modeling and Simulation Office, and the Office of the Secretary of Defense for Program Analysis and Evaluation.

Findings

Technology

The study focused on four different types of simulation for training: (1) *live simulation,* (2) *stand-alone single-system* simulation, (3) *virtual simulation*, and (4) *constructive simulation.* Simulation is used for reasons such as cost, to overcome practical constraints, for safety, to gain good feedback during training, to overcome training limitations, and to protect the environment. Simulation is limited by its fidelity, but within its limitations is an effective and less expensive alternative to live training. Simulation technology is steadily advancing, but current technical challenges include development of a common architecture and accurate representations of the full spectrum of weapon systems, operating environments, and human behavior.

Training Effectiveness and Cost

Today, the Services fully accept the value of live simulation, have adopted several, and are developing others. Although live simulation does not reduce the costs associated with operating and maintaining actual weapon systems, it frequently reduces the cost of using live munitions, and there is substantial evidence that it saves lives and enhances readiness.

The Services make extensive use of stand-alone single-system simulators. They are an important, proven, and well-accepted component of military training. Several authoritative reviews concerning the effectiveness and cost of flight simulators show that, in aggregate, simulators provide significant beneficial transfer from simulator to aircraft at a median operating cost of about one-tenth of an aircraft. Students trained using maintenance simulators perform about as well as those trained with actual equipment, but simulators cost a fraction of the equipment they represent.

The evidence concerning virtual simulation remains incomplete but, for whatever questions remain, it is generally agreed that it has the potential to provide collective training and battle experience *and* do it cost-effectively. This potential has encouraged the Services to project its success and to invest in it accordingly.

There are several hundred computer-based constructive simulations. All of the Services use constructive simulations to support analysis and staff training exercises. The continued widespread use of constructive simulation reflects consensus within the Services that the simulations are valuable.

Levels of Investment

Cost data on simulation are not reported regularly or consistently. This makes it difficult for OSD to discern trends in costs for different types of training or to direct R&D toward areas of highest payoff. By drawing data from a number of different sources and making certain assumptions, it is possible to make rough estimates. An independent estimate made by DMDC as part of this study put total OPTEMPO for FY94 at about $8.2B; $6.0B for flying hours (all Services), $1.36B for steaming days (Navy), and $.84B for vehicle miles (Army). The approximate relative levels of investment for the four types of simulation are stand-alone single-system simulation ($2.4B), live simulation ($0.7B), virtual simulation ($0.4B), and constructive simulation ($30M).

Simulation Programs and Plans

The Services have a multitude of simulation programs covering the four categories of simulation, but much of their planned technology development work is in the areas of virtual simulation and range instrumentation. Each also has one or more generic technology development programs aimed at improving the capabilities of all classes of simulation.

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Tasking

The Committee on Armed Services of the House of Representatives, 103rd Congress, directed the Secretary of Defense to prepare a report on the value of simulation and the potential training efficiency from increased use of simulation (Congress of the United States, 1994). In its tasking, the Committee expressed the belief that declining training resources made it important to optimize training and to increase skill proficiencies more effectively and efficiently. The Department of Defense (DoD) was directed to quantify the impact of simulation technology on military training to determine whether (1) level of investment is appropriate and (2) significant savings are possible.

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Method

This report is based on several recent analyses performed by the Institute for Defense Analyses (IDA), the Defense Manpower Data Center (DMDC), the Defense Modeling and Simulation Office (DMSO), and the Office of the Secretary of Defense for Program Analysis and Evaluation (OSD [PA&E]). Data sources include technical reports relating to training and cost-effectiveness, meta-analyses conducted by IDA, budgetary and defense marketplace reports, and the results of a survey of the use of simulation in the Services conducted by OSD (PA&E). The list of references at the end of the report indicates the scope of the data sources used.

Report Overview

This report is organized in five sections, each focusing on one or more of the study's objectives. *Introduction* presents a simulation overview and describes the capabilities and limitations of simulation for training. *Simulation Training Effectiveness and Cost* summarizes the evidence relating to the training effectiveness and cost of simulation for military training. *Levels of Investment in Simulation* estimates the current levels of Service and DoD investment in simulation. *Simulation Programs and Plans* provides an overview of simulation in the Services. *Conclusions* summarizes the DoD experience with simulation, describes the need for more cost-effectiveness data, presents some key DoD initiatives, and estimates the potential for increased use of simulation.

Readiness

The Clinton Administration has made the readiness of the U.S. armed forces a top priority. President Clinton recently stated, "I have pledged that throughout the life of this administration, our military will remain the best-trained, the best-equipped, the best-prepared fighting force on earth" (Clinton, 1994). On several occasions, leaders in DoD have restated this policy. Members of Congress have supported the policy, and there is little doubt that those both in and out of the present Administration agree that readiness is critically important. Simulation has important readiness implications. Used properly, it enhances readiness; used improperly, it has the opposite effect. The use of simulation is a complex subject and there are no simple answers where setting policy for its use is concerned. This report attempts to provide sufficient background information, research evidence, and cost data to clarify the issues facing DoD.

Simulation is a critical technology for increasing defense readiness for a wide variety of missions. It is of particular importance in the present climate of declining resources. DoD established DMSO to serve as the focal point for Defense modeling and simulation policy, plans, and standards. Early in 1995, DMSO published *DoD Master Plan for Modeling and Simulation (draft),* which establishes DoD-wide modeling and simulation objectives; provides a comprehensive framework for planning, programming, and budgeting modeling and simulation projects, programs, and activities; and assigns responsibilities for the plan's implementation. The plan provides a systematic process for analyzing modeling and simulation requirements; assessing technology developments; developing a common high-level architecture for Defense models and simulations; verifying, validating, and accrediting models; and managing modeling and simulation programs throughout their life cycles. DMSO is presently developing the *Defense Modeling and Simulation Investment Plan*, which will focus DoD's investments in areas with the greatest potential payoff. The plan will be based in part on the results of a series of studies that will answer questions about the cost-effectiveness of emerging modeling and simulation technologies. It will help guide R&D and ensure that DoD programs meet the needs of the active and reserve components of the Services.

Background

Simulation Applications

Common applications of simulation are training, mission rehearsal, testing and evaluation, modeling for acquisition, and combat effectiveness analysis. Note that this report focuses exclusively on the *training* application.

Military Training Taxonomy

Military training generally occurs in one of two settings: *school* or *unit*. Schoolhouse training is structured and usually occurs in a classroom. Unit training occurs in the unit, often using actual equipment.

There are two general types of military training: *individual* and *collective*. Individual training focuses on tasks performed by the individual; for example, aiming a weapon or troubleshooting an electronic system. Collective training focuses on tasks performed collectively by groups of individuals (e.g., crews, teams, units) who must work together and coordinate their activities; for example, conducting a battalion-level attack on a military objective.

Training setting and type of training cross to form a four-element taxonomy (Table 1) (Gorman, 1990). The taxonomy illustrates the many ways that training can occur. Concrete examples of each of the four classes of training are given in the cells of Table 1.

Table 1

Training Setting and Type of Training Cross to Form a Four-Element Taxonomy. The taxonomy helps illustrate the many ways that training can occur. (Adapted from Gorman, 1990).

		Training Environment	
		School	**Unit**
Type of Training	**Individual**	1. Participation in a course at a resident service school, learning to troubleshoot with a maintenance simulator, flight training	2. Participation in a class conducted by a supervisor, supervised on-the-job training, practicing tank gunnery using operational equipment
	Collective	3. Naval damage control training, tank crew drills, formation flying	4. Unit training in the field, unit training with networked simulators, joint and coalition exercise.

Simulation is used in all of these four classes of training. Historically, simulation has been used most extensively for individual training in school (cell 1), although it is commonly used in the other classes as well.

Types of Simulation

There are many different types of simulation. A number of different and sometimes confusing classification schemes are used to describe them. To help sort this out, it is useful first to consider simulation in terms of *people* and *systems*, and second whether the simulation represents both, neither, or either one. (A person who participates in a simulation is of course real, but other participants may be either real or simulated.)

Live simulation combines real people and real systems, generally in a many-on-many environment. Typically, what is simulated is a military engagement involving friendly and opposition military forces that interact realistically on the battlefield with real personnel, weapons, and support systems. These simulations support both individual and collective training, usually at the unit level. In some cases the weapon systems are instrumented such that their relative position and interactions with other combatants can be recorded and replayed in after-action reviews. Examples are the Army's National Training Center (NTC) at Fort Irwin, California; the Air Force's Red Flag range in Nevada; and the Navy's Top Gun facility in Miramar, California.

The combination of real people and simulated systems takes different forms, depending upon what is being simulated. The simplest case is the *stand-alone single-system simulator*. Stand-alone single-system simulators permit real people to interact with simulated systems, typically in a one-on-one environment. These simulators range from simple devices (such as rifle marksmanship trainers) to more complex devices (such as tank gunnery simulators, sophisticated flight simulators, and maintenance simulators).

Virtual simulation involves real people interacting with simulated systems in a many-on-many environment. Simulators are networked together, making it possible for training personnel to interact with one another using simulated weapon systems in an electronic "virtual battlefield."[1] Virtual simulation supports both individual and collective training, usually at unit level. It offers the best opportunity for trainees to interact with each other and their weapon systems, on any chosen battlefield, in real time, without the logistical constraints associated with employing real ships, planes, and ground vehicles. It provides the freedom to experiment, to run many iterations, and to improve coordination among participants. Virtual simulation is the newest type of simulation. Examples are the Army's SIMNET (simulator networking) and Close Combat Tactical Trainer, the Navy's Battle Force In-port Trainer, and combined Services' Multi-service Distributed Training Testbed.

Constructive simulation combines simulated combat forces and simulated systems. It is a computer-based model of combat in which combat systems are controlled by formal rules of movement, engagement, and casualty resolution. Its primary value is in training command staffs, which are usually involved in Joint and Service operations. These simulations usually represent an unfolding battle on a computer screen symbolically rather than literally. Constructive simulations put staff elements in combat training situations where the results of strategic, operational, and tactical decisions associated with specific military missions are assessed. They are usually used to help commanders and their staffs improve individual skills in planning and executing battle plans. They provide commanders and staffs with feedback relating the results of command decisions to battle outcomes. Their primary benefit is in enabling commanders to experiment with options without the cost of fuel, ammunition, and military personnel. They can produce a complete record of actions, outcomes, and the quality and type of training provided and where improvements are needed. There are hundreds of different constructive simulations. Although each of the Services has developed constructive models to meet its command staff training needs, few models support Joint training; examples are Janus, Joint Theater Level Simulation, Enhanced Naval Wargaming System, and Air Warfare Simulation.

[1] Virtual simulation is also known as *distributed interactive simulation* and *advanced distributed simulation*. To avoid confusion, this report uses the virtual simulation terminology.

Another form of simulated people and simulated systems is computer-driven *semi-autonomous forces* in a virtual simulation. Virtual simulation may be designed to enable participation by simulated as well as real people. Many virtual simulations have this capability as a way of increasing force sizes without increasing the number of people involved.

Capabilities of Simulation

Simulation is used for reasons such as cost, to overcome practical constraints, for safety, to gain good feedback during training, to overcome training limitations, and to protect the environment.

Generally, simulators *cost* less than operational equipment to use and can result in significant economies in training. For example, flight simulators cost roughly one-tenth of the aircraft they simulate, but can be equally effective for some portions of flight training.

Simulators enable people to do things that *would otherwise be impossible*. For example, in preparing for an assault it is not possible to practice in enemy territory, but simulation permits friendly forces to penetrate, traverse, and maneuver in virtual environments representing enemy airspace or terrain--movements impossible by any other practical means; this technique was used to great effect during the Persian Gulf War.

Simulation is used for *safety*. It can be used to do things that are too dangerous to practice with operational equipment. Examples are autorotation to landing of a helicopter whose engine has failed or simulating non eye-safe lasers whose use is restricted except in combat.

Simulators can in some cases provide *better feedback* to users than the systems they represent. For example, they can be instrumented to collect performance data automatically, to display that data for training purposes, and to play back performance data at high speed.

Simulation can overcome *practical limitations* of live training. For example, simulation can present a 360-degree battlefield, with unpredictable targets, an option unavailable for reasons of safety and limited resources on a training range. It is much more economical to represent a large force in a simulation than with a live force; planning, scheduling, and logistics are also greatly simplified.

Environmental restrictions limit the ability to perform certain types of combat training, such as electronic warfare and realistic weapon employment training. The military must restrict its maneuvers to certain training areas, limit maneuver damage and pollution (e.g., noise, smoke, dust), protect endangered species, and respect historical and cultural restrictions. Simulation does not endanger the environment and, to the extent that it supplants live training, environmental constraints no longer limit training.

Today's economic, political, and military conditions make it difficult for DoD to train without simulation. Moreover, simulation permits military trainers, operators, planners, and engineers to use the same combat simulations to work through problems, thereby improving integration and support among defense communities.

Limitations of Simulation

Simulation has limitations as a replacement for operational training. A simulation imitates something else and is limited by its fidelity--its ability to represent the important attributes of the actual system. The greater the fidelity, the better the simulator serves as a surrogate for an actual system. Because simulation is not "the real thing," there are cases where simulators cannot accurately represent combat systems or the combat environment. Fidelity can be considered along dimensions such as scope, stimulus, response, and process.

Military jobs are defined in terms of job tasks. A simulator is seldom sophisticated enough to permit training on all job tasks within a particular military occupational specialty; its *scope* is limited. It might, for example, be useful for training 20 percent of the tasks. This is a basic limitation of all simulators. Whatever simulation does not cover must be trained using actual equipment.

Simulators present *stimuli* to their users through their displays. For example, a flight simulator presents visual stimuli in the form of a view of the external world as seen from the cockpit as well as instruments and displays within the cockpit. The fidelity of these displays may approach but will seldom match that of an actual cockpit during flight. Flight simulators have a limited capability to represent the complex conditions involved in tactical aviation, such as the acceleration forces resulting from high-speed maneuvers and concomitant problems associated with spatial-temporal awareness. Simulators can also cause a type of disorientation known as "simulator sickness" if visual and motion cues are not carefully synchronized. However, there are many cases where a weapon system operator interacts with the external world primarily through an indirect visual display such as a radar screen or a thermal image in a sighting system. In these cases, the simulated display could be virtually indistinguishable from the real thing. A simulator may also attempt to present other types of stimuli (e.g., physical motion and acceleration associated with high G levels, vibrations, and aircraft noises).

The user operates a simulator with its controls. Their *response* mimics that of the actual system. Response fidelity is limited by how accurately the simulator's controls and their responses represent those of the actual system. For several years there has been a trend for systems to become increasingly computerized; this generally makes them easier to simulate accurately.[2]

Typically, a user will interact with simulator in a *process*. For example, a computer-based simulation of a military campaign might permit its users to gather intelligence, deploy forces, engage the enemy, and perform other necessary combat functions. The simulation is limited by how well it enables the user to perform the functions realistically.

[2] A concrete example is the evolution in aircraft from mechanical to computer-mediated ("fly by wire") controls.

Within its limitations, simulation is an effective and less expensive alternative to live training. If simulation is overused at the expense of OPTEMPO (operating tempo--live training), training and readiness will suffer. The key is to find and use the mix of simulation and live training that provides acceptable military readiness at the lowest cost.

Evolution of Simulation Technology

As simulation technology has advanced, so has the ability to blend the various types of simulations together into a so-called *seamless simulation;* simulation technology still has to overcome technical hurdles to in order to include all combat forces and platforms. Technical challenges include development of a common architecture and accurate representations of the full spectrum of weapon systems, operating environments, and human behavior. The intent is to allow the most effective combination of real and simulated people and real and simulated systems for the type of training required at each level in the military force. For example, real people sitting in front of real displays on board a ship could react to signals generated by real pilots flying simulated aircraft in a virtual battlefield. These pilots could be engaging ground targets which are being controlled on virtual terrain as an element of a large enemy force within a constructive simulation. Their visual reports could form the basis for conducting sea-based Naval gunnery strikes on an enemy breakthrough location, and for redirecting simulated ground forces into a blocking position. One example of this approach is the Army's Force XXI Training Program, whose purpose is to devise an optimized combined arms training strategy using live, constructive, and virtual simulation.

Other emerging technologies are also important to simulation. Improved high-resolution video capture and display technology is needed to increase visual fidelity. Virtual reality technology is promising as a means to increase simulation realism. A recent review of the value of simulation for training identified several other technologies which are currently being developed in support of simulation, including networks, semi-automated forces, terrain and environment, range instrumentation, individual combatants, virtual environments, and training technology (Orlansky, Dahlman, Hammon, Metzko, Taylor, & Youngblut, 1994).

The major new development in simulation is virtual simulation. Its successful development depends upon supporting technologies such as networking protocols; improved displays; virtual reality; representation of terrain, environment, and forces; and semi-automated forces.

SIMULATION TRAINING EFFECTIVENESS AND COST

This section summarizes evidence relating to training effectiveness and cost by type of simulation: live simulation, stand-alone single-system simulation, virtual simulation, and constructive simulation. The evidence is of two general types: (1) published research evidence and (2) Service use of simulation. Service use of simulation is usually based on cost-effectiveness analyses, though such studies are not always published in the open literature.[3] Both types of evidence are useful in estimating simulation cost-effectiveness.

Live Simulation

The amount of combat experience profoundly affects both the probability of future combat success and of survival. Historical data from World War II show that in air-to-air combat, the probability of being shot down was greatest on the first combat, but dropped dramatically on subsequent engagements (Gorman, 1990). Analogous data were reported for undersea combat. The value of combat experience is well documented, but the cost of such learning in terms of combat losses is severe.

During the 1965-68 period of the Vietnam War, U.S. fighter pilots lost about one plane for every two enemy losses. In 1968, the Navy instituted its *Top Gun* Fighter Weapons School, a live simulation, to train its pilots how to engage enemy fighters. During 1970-73, the Navy increased its kill ratio in air-to-air combat to 12:1. Naval officers attributed the Navy's combat success to the experience gained in Top Gun (Gorman, 1990). The improved kill ratio is based on combat against North Vietnamese pilots, not an estimate from training exercises.

Live simulation may be viewed as simulation of war sufficiently realistic, unpredictable, challenging, and stressful that it enables the Services to gain a close approximation of combat experience in peacetime. It thereby substitutes simulation casualties for the casualties suffered in combat. Warriors with this experience are thereby able to enter their first real combat with the equivalent of combat experience. The Army's NTC uses live simulation to train ground combat forces against live and very experienced opponents. Training received at the NTC proved its value during the *Battle of 73 Easting* during Operation Desert Storm.[4] On the second day of the ground war, an American Force, outnumbered three to one, destroyed an opposing force on its own ground. Leaders of the American Force, none of whom had prior combat experience, declared that their participation in simulated wars at the NTC and Combat Maneuver Training Center (CMTC) had in effect provided them with combat experience (Orlansky, 1993).[5]

Today, the Services fully accept the value of live simulation, have adopted several, and are developing others. For example, Army live simulations are the NTC, CMTC, and the JRTC (Joint Readiness Training Center). The Navy has Top Gun, and the Air Force has adopted its equivalent school, *Red Flag*. The Navy uses Tactical Air Combat Training System ranges to train pilots in intermediate and advanced air-to-air combat skills, and agreements among the Services will extend the use of these ranges to the Air Force and Marine Corps.

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[3] A Service may support some simulations based on less than scientific evidence. Nonetheless, a Service's adoption of a particular simulation reflects the endorsement by senior Service decision makers of the efficacy of that simulation.

[4] *73 Easting* is a location in the Iraqi desert where the U.S. Second Armored Cavalry Regiment fought elements of the Iraqi Tawakalna Division on 26 February 1991.

[5] During a debrief following the battle, a senior commander asked an American platoon leader who had participated in the battle how his unit had been so successful in its first combat engagement. The platoon leader replied, "Sir, this was not our first battle. This was our fifteenth battle! We fought three wars at the National Training Center...and a lot of other simulations like SIMNET...This war was just like our training" (p. 33).

Live simulation involves real people and real systems and hence does not offer an opportunity for cost savings via a reduction in OPTEMPO. Although live simulation does not reduce the costs associated with operating and maintaining actual weapon systems, it frequently reduces the cost of using live munitions, and there is substantial evidence that it saves lives and enhances readiness. The Army's view of this is that "the trade-off value for live simulations tends to be in a significantly higher level of training readiness rather than the dollars saved" (Department of the Army, 1993). Live simulation's effectiveness is its demonstrable payoff in combat success and reduced casualties. The Services strongly support live simulation and have invested heavily in the technology.

Stand-Alone Single-System Simulation

No one has counted up the total number of stand-alone single-system simulators in use in the Services, but the number is probably in the thousands. At the lower end of this spectrum, many of the simulators are, in fact, little more than training aids intended for use in a classroom or laboratory. Formal studies to assess cost-effectiveness of simulators are required only if cost exceeds a fairly high cost threshold (typically representing a total RDT&E cost well in excess of \$100M). Many less costly simulators are adopted without undergoing rigorous testing, although their continued use reflects consensus within the Service that the simulators are performing adequately. Cost-effectiveness data are more readily available at the middle to upper end of the spectrum, particularly for flight and maintenance simulators.

Several authoritative reviews concerning the effectiveness and cost of flight simulators show that, in aggregate, simulators provide significant beneficial transfer from simulator to aircraft at a median operating cost of about one-tenth of an aircraft (Orlansky & String, 1977; String & Orlansky, 1977; Orlansky, Knapp, & String, 1984).[6] Because of their scope, the reviews probably provide the strongest case for the value of *any* type of simulation.

Students trained using maintenance simulators perform about as well as those trained with actual equipment, but simulators cost a fraction (approximately 38 percent) of the equipment they represent. In studies where time to train was reported, training with simulators took 25-50 percent less time than with actual equipment (Orlansky & String, 1981).

The Army uses simulators in lieu of some actual gunnery, flight, and field training. It estimates that it substitutes simulation for \$68M of flight operations training in the active force and \$55M in the Reserves each year. In tank gunnery, the introduction of the Conduct of Fire Trainer reduced the annual expenditure of ammunition from 134 to 100 rounds per tank and improved marksmanship. The new Tank Weapons Gunnery Simulation System is expected to reduce the annual consumption to 78 rounds, for an additional saving of \$50M each year (Orlansky et al., 1994).

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[6] Orlansky et al. (1994) report that these findings have been supported with a 1992 review of 15 more recent studies.

The Navy uses simulators as prerequisites for specific training requirements and in flight training programs. It considers flight simulators to be limited as viable substitutes for operational flight hours, but estimates that simulators contribute an overall two percent to Primary Mission Readiness (PMR, the number of flight hours required by an aircrew to remain current and qualified to perform assigned missions) (Department of the Navy, 1993). As a result, the Navy budgets for two percent of its flight training to be conducted in flight simulators.[7] The Navy considers simulation to be effective in initial training in unfamiliar aircraft, as is reflected in the ratio of simulator to actual aircraft training flights (40 to 77) in the fleet replacement training program for F/A-18 aircraft (Orlansky et al., 1994). Flight simulators are currently limited in their ability to represent live combat, but technological improvements are expected to increase the number of combat tasks they can train. The Navy has not set a minimum frequency of flight needed to assure safety and prevent loss of pilots and aircraft. The amount that can be substituted for OPTEMPO savings cannot be predicted with certainty based on the current state of knowledge.

The Air Force Air Mobility Command plans to replace up to 50 percent of flight training hours with flight simulators and other training devices for training air transport crews. In contrast, the Air Combat Command views flight simulators as complementary to the flying hour program and not as a substitute for training fighter and bomber crews. The Air Combat Command will procure 97 low-cost simulators using new technology and will locate them at flying bases in order to improve training readiness (Orlansky et al., 1994).[8]

The Air Force correlated the number of combat aircraft training sorties per month with the number of class A training mishaps per 100,000 flying hours. The data suggest that an acceptably low accident rate is achievable by maintaining a training sortie rate of at least 20 per month (Department of the Air Force, 1993). Simulation technology has advanced considerably in the period covered by these data (1973-1993). Hence, the ability to simulate combat aircraft has probably improved, although no simulation can produce sustained high G force maneuvers. If actually experiencing these maneuvers is necessary for combat proficiency and flight safety, then the minimum acceptable OPTEMPO level to satisfy this requirement needs to be maintained.

The Services make extensive use of stand-alone single-system simulators. They are an important, proven, and well-accepted component of military training.

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[7] Navy Flying Hour Program requirements are based on a strictly developed curriculum called the "Squadron Training and Readiness Matrices" which lays out specific tasks on an annual basis for each type of aircraft by mission.

[8] There is a difference in philosophy between Air Mobility Command and Air Combat Command regarding the use of flight simulators for mission training. The difference is based in part on differences in requirements for simulating flight characteristics and mission profiles of the aircraft in each command. The flight characteristics of the Mobility Command more closely resemble those of commercial air transports than do those of the Combat Command, which focuses on high G combat maneuvers.

Virtual Simulation

Virtual simulation is the newest and least proved of the simulations; it is also the leading-edge simulation of the present day. Because virtual simulation is new, the Services have limited experience assessing its cost-effectiveness. Live simulation, as well as constructive simulation, have existed in some form since antiquity. Today's versions of these simulations incorporate the latest technologies, but are conceptually similar to their earliest versions. Stand-alone single-system simulators have continued to evolve, but remain limited by their inability to support training of staffs, units, and larger military personnel collectives. Virtual simulation takes this additional step by networking separate simulators together and permitting their personnel to interact. Moreover, it generates a record of what every vehicle did during every moment of the exercise, which enables fast and accurate feedback to participants.

Evidence concerning the cost-effectiveness of virtual simulation is incomplete, although it is encouraging. The first virtual simulation, SIMNET, was developed with Advanced Research Projects Agency (ARPA) support during the 1980's to test the virtual simulation concept. Experience with SIMNET was positive enough that the Army decided to develop a more sophisticated successor, the CCTT (Close Combat Tactical Trainer). Analysis indicated that SIMNET could train tank crew members on about 35 percent of the tasks required by the Army; the CCTT covers about 60 percent of tasks.[9] Over 80 percent of the cost of exercises at the NTC goes for transportation from the home station to the NTC and return, and for ammunition and related expenses; the use of virtual simulation avoids all of these costs (Angier, Alluisi, & Horowitz, 1992).

Orlansky et al. (1994) recently conducted the most comprehensive analysis to date concerning the status, cost-effectiveness, and potential of Virtual Simulation; the following comments are contained in the study report:

> [Virtual simulation] has great potential for improving training at unit, Service, and Joint levels. [It] creates an environment in which units of all sizes (e.g., Army and Marine battalions, brigades, or divisions, Air Force squadrons, and Naval task forces) separately or in combination, can engage in two-sided, real-time combat exercises, very much as if they were involved in a conventional large-scale field exercise on a well-instrumented range.... Training exercises conducted with [virtual simulation] are likely to be cost-effective, compared to live field exercises.... Several tests conducted with SIMNET suggest that CCTT will be an effective training device.... When measured by the scores obtained on 55 tasks specified by ARTEP, platoons trained in SIMNET performed as well in three field exercises as those who received conventional field training.... For a given subset of tasks that are fully represented in SIMNET, and within a given amount of time, SIMNET training is more effective than additional field exercises.... Platoons with more

[9] The Army's training standards are set by the ARTEP (Army Training Evaluation Program), which specifies what tasks soldiers must be capable of performing, along with conditions and standards. The task data were summarized in Orlansky et al. (1994), and are based on analyses conducted by the U.S. Army Research Institute for the Behavioral and Social Sciences and the TRADOC Analysis Center.

> battle runs on SIMNET produced higher scores on the competition for the Canadian Armor Trophy.... SIMNET training on a field scenario improved field performance.... No known instance of SIMNET training produced negative results (pp. V-1 - V-4).

Orlansky et al. also note that many of the SIMNET evaluations have methodological limitations based on which "issue may be taken" with their outcomes. Further tests will be needed to obtain conclusive answers regarding cost-effectiveness. Evaluation of virtual simulation is difficult. Experience is limited because, until recently, no such simulations existed. It is also costly to conduct tests involving large numbers of participants and data collection personnel.

Virtual simulation offers the best opportunity for people to interact with each other and their weapon systems, on any chosen battlefield, in real time, without the logistical constraints of employing real ships, planes and ground vehicles. It provides the freedom to experiment, to run many iterations, and to get the kinks out of the coordination requirements with other members of the force or with other Services. It is not yet clear what combination of simulation and OPTEMPO normally will be needed to maintain readiness; the data have not yet been generated

The Army's CCTT program, a follow-on to SIMNET, was approved with the idea that when it became operational, operations and maintenance (O&M) cost savings would pay for the CCTT in the FY 2000 to 2005 Future Years Defense Programs (FYDP) (Department of the Army, 1993). This decision was based on encouraging results from evaluations with SIMNET, the precursor system.[10] An early evaluation of CCTT "Quickstart" modules and a preliminary evaluation taking place currently using SIMNET as a surrogate and performance at the CMTC as the measure of effectiveness will provide the cost-effectiveness data necessary to determine specific trade-off between simulator time and tank miles. This will be the first major DoD study to quantify the benefits of virtual simulation. The training effectiveness of virtual simulation is still being determined, but the Army has demonstrated its confidence in the technology.

The Army's Force XXI Training Program (previously known as the Virtual Brigade) is a $34M program to devise an optimized combined arms training strategy using live, constructive, and virtual simulation. The first unit to test this program will be the 2nd Armored Division as it prepares for its NTC rotation in May 1996.

The Multi-service Distributed Training Testbed (MDT2) is a joint service research and development (R&D) program to evaluate the training effectiveness of virtual simulation for *Joint* training. The initial focus of MDT2 is an assessment of the ability of distributed interactive simulation to support training in close air support missions.

The evidence concerning virtual simulation remains incomplete but, for whatever questions remain, it is generally agreed that virtual simulation has the potential to train collectives

[10] The decision to build the CCTT was based, in part, on encouraging results from SIMNET evaluations. In comparison tests on a range of tasks, trainees trained on SIMNET performed better than those trained using real tanks. The improvement from pre- and post-tests for SIMNET was 20% and for field training was 3%.

and provide battle experience *and* do it cost-effectively. This potential has encouraged the Services to project its success and to invest in it accordingly.

Constructive Simulation

There are several hundred computer-based constructive simulations.[11] These include such simulations as *Janus*, which is used to conduct analytical studies of doctrine relating to strategy, policy, and weapon system development and to train junior leaders to synchronize the battlefield; *Corps Battle Simulation*, used to train corps, division, and brigade staffs; *Joint C3 Simulation*, a research and evaluation tool which models air and land component forces, terrain features, and their interactions; *Air Warfare Simulation*, which trains senior NATO commanders and their battle staffs to execute Joint and combined operations; and many others.

All of the Services use constructive simulations to support analysis and staff training exercises. For example, the Army's family of simulations supports company through corps commander and battle staff training. The Army considers these to be good staff trainers and exercise drivers, but does not believe that they reduce the need to go to the field. Personnel need to physically set up tactical operations centers, exercise communications equipment, and perform tasks in a physically demanding environment similar to war. The continued widespread use of constructive simulation reflects consensus within the Services that the simulations are valuable.

In 1992, constructive simulation was used as a partial substitute for actual troop deployments in the REFORGER (Return of Forces to Germany) exercise in Germany, avoiding \$34M in costs over the equivalent exercise done without simulation in 1988. Training of staffs and planners involved was also improved.

The most extensive use of simulation for Joint training is in the U.S. Atlantic Command (USACOM). Prior to 1993, USACOM performed Joint training with very large and costly annual exercises. Their new simulation-based program enabled the permanent cancellation of *Ocean Venture* and *Solid Shield*, freeing approximately \$35M annually in O&M and Joint transportation funding. The O&M and Joint transportation resources, which used to serve only the relatively small slice of CONUS forces in Ocean Venture or Solid Shield, will be used much more efficiently by a much wider audience.

USACOM's Joint Training Analysis and Simulation Center will use constructive and virtual simulation to conduct battle laboratory assessments of current readiness and doctrine and to conduct crisis rehearsals. The same technologies promise to deliver the capability to insert virtual prototypes of new systems into the exercise and rehearsal environments in support of the weapon systems acquisition process. Such new applications increase the value of simulation technologies.

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[11] The Joint Chiefs of Staff *Catalog of Wargaming and Military Simulation Models (12th. Edition)* (1993) lists 528 different models, all of which are currently in use.

LEVELS OF INVESTMENT IN TRAINING-RELATED SIMULATION

This section estimates DoD's investment in simulation. It estimates the total investment in simulation and training and breaks down the cost data by training and contract expenditures. Contract expenditures, in turn, are broken down by sector (RDT&E, procurement, and services) and military Service. Where possible, an attempt is made to scope costs by type of simulation. It is impossible to make precise estimates because of the lack of available data, but the final subsection makes order of magnitude estimates based on reasonable assumptions. This report uses total program costs, where they are identified. It does not intentionally include government or military personnel costs, but some of the informal estimates of cost may include some "base support" type costs.

Cost data on simulation are not reported regularly or consistently. This makes it difficult for Office of the Secretary of Defense (OSD) to discern trends in costs for different types of training or to direct R&D toward areas of highest payoff. This section makes estimates based on the best available data. Unless this report indicates otherwise, costs presented have been converted to constant FY 1995 dollars, using DoD deflators published in the National Defense Budget Estimates for FY 1995 (Department of Defense, March 1994).

School and Unit Training

Table 1 illustrated that military training may occur in two settings (school or unit) and be of two types (individual or collective), resulting in four general classes of training. Simulation may be used in any of the four classes of training. In most cases it is impossible to determine the relative investment in simulation versus training, although it may be possible to make rough estimates.

Individual Training in School. This is the cost of fulfilling Congressionally authorized student loads for the active and reserve components of the armed forces. The estimated FY95 cost is approximately $14B (Department of Defense, 1994). This total cost includes pay for military personnel of $8.6B and base support costs of $3.1B, leaving $2.3B as "direct" cost.

Individual Training in Unit. This is the cost of formal and informal on-the-job, familiarization, and cross-training in the unit. This cost is unknown.

Collective Training in School. This is the cost of training crews, teams, units, and larger personnel collectives in formally structured settings. The total cost is unknown, but a significant portion of this training involves live simulation, for which some cost estimates are available. A portion of this training involves the use of instrumented operational systems in simulated combat. The estimated FY95 costs for the Army CTCs $0.5B (Orlansky et al., 1994). The Air Force has reported that it scheduled two *Red Flags*, one *Green Flag*, one *Maple Flag*, and three *Cope Thunder* exercises per year at a cost of approximately $12M (Department of the Air Force, 1993). The FY95 cost of the Navy's *Top Gun* has been estimated to be approximately $18.2M (Department of the Navy, 1995). Neither the Air Force or Navy estimates include infrastructure support or range costs. The Army, Navy, and Air Force estimates clearly include different cost elements; for example, some include the cost of base operations but others do not, and the authors were unable to normalize the data.

Collective Training in Unit. This involves crew and unit training at all levels within the Services and includes unit training, OPTEMPO, and Joint exercises.

Most *unit training* occurs in operational units and commands, and is supported by funds in the O&M accounts. This cost is estimated to be $13.3B in FY95 dollars (Logistics Management Institute, 1993).

It has been estimated informally that collective training in operational units costs $40 to $50B each year (Orlansky, 1995). The actual cost is not clear because different estimates may include different cost elements and commanders have great discretion in how they expend the O&M funds which ostensibly underwrite OPTEMPO

In addition to Service training exercises, the Commanders in Chief of the Regional Commands also conduct *Joint training exercises*. These exercises prepare Service personnel to function as an integrated Joint Task Force. Joint exercises include training to develop and assess Joint readiness (i.e., preparation for the ways in which forces of different Services will operate together). This cost is estimated for FY95 to be $434M (Orlansky et al., 1994). These costs are primarily for transportation of forces and equipment to and from exercises. Expenses incurred during the exercise are funded out of the Service's operating budgets.

OPTEMPO is the amount of mission performance operations and live training that each Service budgets to conduct each year. OPTEMPO is expressed in terms of the average number of flying hours per aircraft, steaming days per ship, or miles traveled per vehicle. It includes the costs of fuel, consumption of spare parts, and maintenance and related activities associated with operations and training. An independent estimate made by DMDC as part of this study put total OPTEMPO for FY94 at about $8.2B; $6.0B for flying hours (all Services), $1.36B for steaming days (Navy), and $.84B for vehicle miles (Army). The relative costs of each of the three types of OPTEMPO varies greatly, according to a number of different estimates, but flying hours is always the major contributor. The training portion of OPTEMPO is the largest single training-related investment, but DoD currently lacks a method to relate amounts and types of OPTEMPO to readiness levels.[12]

Live simulation is a subset of OPTEMPO. Narrowly defined, live simulation refers exclusively to the use of instrumented ranges and weapon systems fitted with instrumentation to

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[12] Angier, Alluisi, and Horowitz (1992) made this 1992 OPTEMPO estimate: flying hours, $11.7B; steaming days, $8.4B; vehicle miles, $1.3B; total OPTEMPO cost (1992 dollars), $21.4B. A 1993 estimate by the Logistics Management Institute put total OPTEMPO at $9.4B (Logistics Management Institute, 1993). Both of these are greater than the recent DMDC estimate. There is insufficient data to resolve the discrepancy among these estimates; it is likely that the different values do not include the same cost elements. OPTEMPO cost is difficult to estimate because it involves so many different elements. It may include elements of unit training, collective training, and joint exercises. The related transportation costs of moving soldiers and equipment to and from training sites account for roughly one-third of OPTEMPO. OPTEMPO also includes repair and depot maintenance costs.

record combat engagement data (e.g., speed, direction, location, weapon usage). The costs of participating in live simulation are funded from OPTEMPO resources. More broadly defined, live simulation could be considered to include the field exercises that commanders use to train their personnel and which do not involve instrumentation or instrumented ranges. In its report to Congress, the DUSD [R] (1995) used a very broad definition and estimated the cost of live simulation to be equivalent to the most credible and recent OPTEMPO figures; that is, those provided by the independent DMDC estimate (FY94 total of $8.2B; $6.0B for flying hours, $1.36B for steaming days, $.84B for vehicle miles).

Investments in Simulation

DoD investments for stand-alone single-system, virtual, and constructive simulation for FY95 are estimated to be approximately $2.75B, with the following expenditures by sector: RDT&E ($0.67B), contractor support ($0.59B), and procurement ($1.5B) (Frost & Sullivan, 1994).[13] These costs exclude in-house expenditures such as base support, administration, and other miscellaneous costs. Contractor support includes complete logistics support for both maintenance and operation of simulators and other training devices; operation of training facilities; and the administration, operation, and maintenance of training activities. Procurement represents the largest portion of expenditures (55 percent). The breakdown by Service is Air Force ($.85B), Army ($.75B), Navy ($.91B), and other agencies ($.26B). Marine Corps expenditures are included in the Navy figure.

The largest portion of these investments is for aviation simulators, which account for $1.174B annually, or 42 percent of the total (Figure 1). It is also the largest in terms of number of contracts, led by the Air Force, which has three major aviation programs (C-17, C-141, Special Operations Forces Aircrew Training System). Investments for non-system training devices and other miscellaneous devices amount to $362M, or 13 percent of the total. No other single segment accounts for more than 7 percent of the total expenditures. Note that this estimate does not include the cost of equipment for use in training that is procured as part of the acquisition of the parent weapon system. For example, procurement of operational training equipment, such as suites of equipment for a new sonar system, can costs tens of millions of dollars each.

[13] All of the data presented in this subsection come from Frost & Sullivan (1994). Its sources include contract award announcements in the *Commerce Business Daily*, DoD RDT&E reports, information gathered at conferences, and other governmental information sources. The report is unofficial and is gathered and sold for marketing purposes, but contains information unavailable elsewhere from any single source.

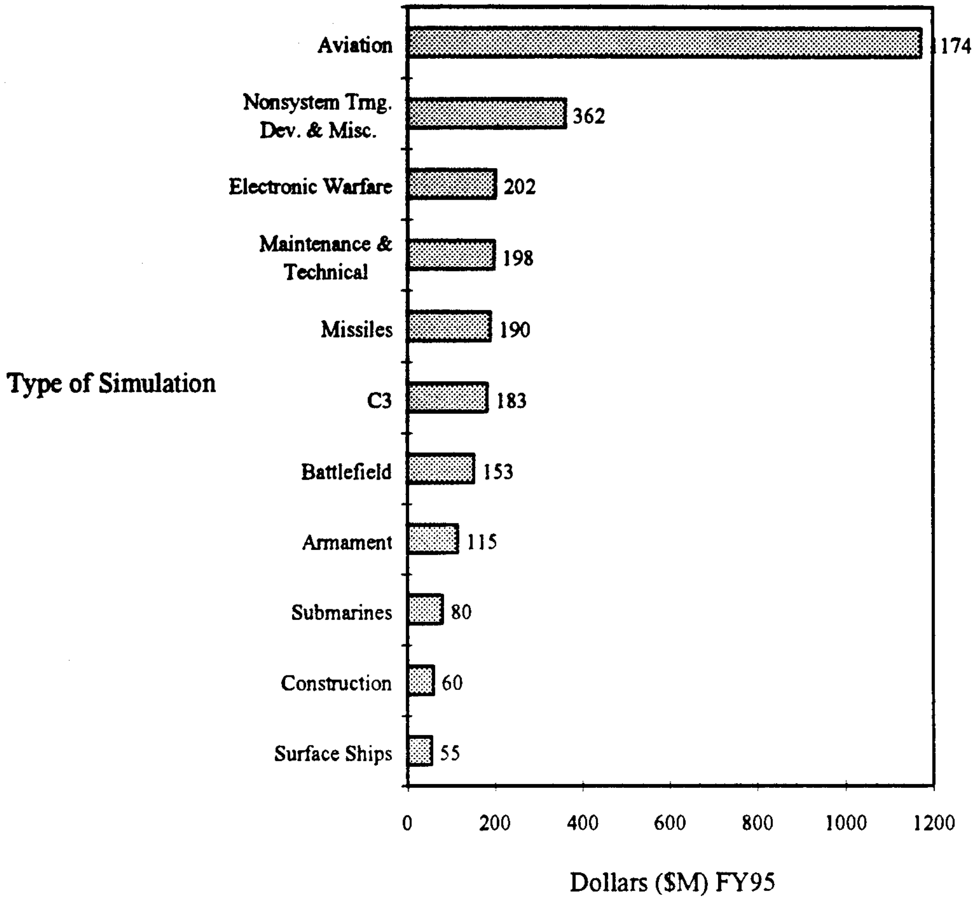

Figure 1. **Estimated annual investments in stand-alone single-system, virtual, and constructive simulation by type in millions of dollars (Frost & Sullivan, 1994).**

Distribution of Investments by Type of Simulation

The data presented above put the yearly total investment for stand-alone single-system, virtual, and constructive simulation at approximately $2.8B. The cost of virtual simulation for FY95 is estimated to be about $375M per year. Additional smaller programs bring the total estimate to about $0.4B per year. The cost of stand-alone single-system simulators can be estimated by reducing the total investment in training devices and simulators by the cost of virtual simulation programs, i.e., $2.4B. DoD invests approximately $30M each year in constructive simulation development.

It is impossible to estimate the investment in live simulation precisely because the data are not reported in a consistent manner by the Services. However, it is possible to lay out what is known and to scope the amount in terms of an order of magnitude. The estimates for live simulation given earlier ($0.5B for Army, approximately $20M each for Navy and Air Force) almost certainly contain different elements of cost, but may represent the respective upper and lower bounds on these costs. The various estimates provided by the Services may or may not include portions of the $8.2B OPTEMPO that contributes in some measure to live simulation.

When adding in the contract costs of developmental systems, it is reasonable to put the cost of live simulation somewhere between about \$0.5B and \$1B, and probably closer to the high end of this range; for purposes of further discussion, let us somewhat arbitrarily set this figure at \$0.7B, while bearing in mind that this is a *very rough, order of magnitude* estimate.

Figure 2 illustrates the approximate relative level of investments for OPTEMPO (\$8.2B), stand-alone single-system simulation (\$2.4B), live simulation (\$0.7B), virtual simulation (\$0.4B), and constructive simulation (\$30M). Though these numbers are rough estimates, the relative levels are quite revealing. DoD spends about three times more on OPTEMPO than on all types of simulation combined.

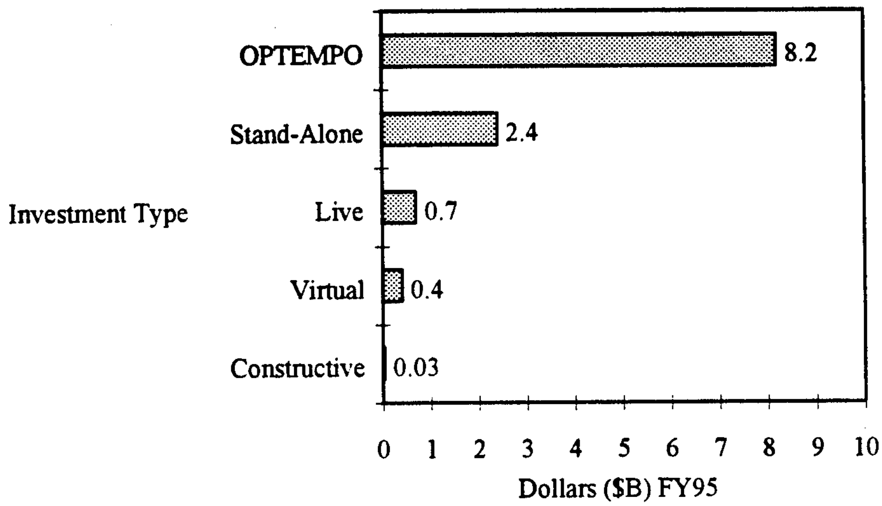

Figure 2. Approximate relative level of investments for OPTEMPO, stand-alone single-system simulation, live simulation, virtual simulation, and constructive simulation.

The area of greatest investment in simulation is for stand-alone single system simulation, particularly for flight training, which accounts for approximately 43 percent of all stand-alone single-system investments (see Figure 1). Investments in live and virtual simulation are an order of magnitude smaller than in stand-alone single-system simulation and in constructive simulation an order of magnitude smaller still.

The Future

The Services spend much more on the live simulation portion of OPTEMPO than on simulation. The question many in DoD ask in these cost-conscious days is whether simulation can be traded for some of that portion of OPTEMPO to save money while maintaining readiness. This is a highly charged question for the Services, which have generally demonstrated reluctance to give up OPTEMPO for *any* reason. Nonetheless, historically the Services have used simulation in lieu of some portion of OPTEMPO, and may be expected to continue this practice in the future.

Is there any reason to expect that the distribution of investments in OPTEMPO and the various types of simulation may change? Some in DoD believe that the answer is yes. The belief is based on the conviction that improvements in simulation technology--and particularly in virtual and constructive simulation--will permit simulation to be credibly viewed as a substitute rather than simply a supplement for live training. DoD is gaining experience with newer, more powerful forms of simulation. If they prove effective, investments in virtual and constructive simulation could more than double over the next few years (DUSD [R], 1995).

The expanded use of virtual simulation will support a greater share of training for tactical air and multi-Service missions, such as close air support, integrated naval-amphibious-ground assaults, operations other than war, and mission rehearsal. Increasing investments in constructive simulation will be needed to improve the availability and cost-effectiveness of Joint and coalition training. These investments should also support the training needs of the Reserve Components and should provide better tools to assess readiness at the unit and Joint levels.

SIMULATION PROGRAMS AND PLANS

This section describes Service programs and plans for future development and use of simulation for training.[14] The Services have a multitude of simulation programs covering the four categories of simulation, but much of their planned technology development work is in the areas of virtual simulation and range instrumentation. Each also has one or more generic technology development programs aimed at improving the capabilities of all classes of simulation. The following is a list of contract-supported simulation activities that are publicly known. There are other activities supported within the Service budgets that are not identified separately in a form currently available to OSD. In what follows, Marine Corps programs and plans are included in the Navy descriptions.

Live Simulation

Navy

The Navy, with Top Gun, was the first Service to use instrumented live simulation to train combat air crewmen. It is currently in the design phase of a new, large scale live simulation system, the Tactical Combat Training System (TCTS). The purpose of TCTS is to provide and evaluate Naval combat training at sea for single platform, multi-platform, and battle force multi-warfare training. Work is planned in developing exercise scenarios, simulating exercise participants and weapons, tracking participants and events, and providing accurate and timely feedback. TCTS will be analogous to the Army's NTC and has a target date for its Initial Operational Capability in the year 2000. Each of the four systems to be purchased will have the capability to handle 100 aircraft, 24 ships, and 6 submarines (Department of the Navy, 1993). This is essentially the instrumentation and associated infrastructure to optimize the training benefit from each hour of live training that currently takes place. The system will be able to mix live and virtual entities and provide feedback on the performance of each member of the force at the completion of a training exercise. TCTS will be used by the Top Gun Fighter Weapons School, the Naval Strike Warfare Center, and the Marine Corps' weapons and tactics instructors course.

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[14] Most of the specific project information discussed in this section was taken from Frost and Sullivan (1994).

The system provides aircrew training in weapons and countermeasures employment and tactics development in air-to-air, air-to-surface, power projection, and defense suppression mission areas through real-time monitoring and post-exercise debrief of aircrews flying on instrumented training ranges. Improvements are currently being made in new aircraft interfaces, weapons and countermeasures simulations, display modifications, and software development.

The Navy blends live and virtual simulation in its Battle Force Tactical Trainer (BFTT), which links the systems of ships anchored at pierside. It involves real people operating real equipment and hence is technically a live simulation. However, the ships are linked using wide area networks and will also operate as teams in a virtual environment.

Air Force

Air Force policy is to use live simulation whenever possible, reserving constructive and virtual simulations for training that cannot be accomplished live (Department of the Air Force, 1993). With the exception of Defense Business Operating Fund for Transport and real-world taskings, the Air Force considers its entire flying hour program to be live simulation. The Air Force has a very active live simulation program consisting of the Air Combat Command's Red, Green, and Maple Flags and the Pacific Air Force's Cope Thunder exercise. Red and Green Flag are designed to provide high threat composite force training. Green Flag emphasizes electronic combat. Exercises usually involve all USAF operational aircraft with the exception of strategic reconnaissance assets. Cope Thunder is intended to provide realistic training for personnel in a simulated combat environment. Maple Flag is similar to Red Flag but is flown from Canadian Forces Base Cold Lake, Alberta, Canada. Typically, there are two Red Flags, one Green Flag, one Maple Flag, and three to five Cope Thunder exercises per year (Department of the Air Force, 1993). The Joint Air Combat Training System is under development and will eventually replace the Red Flag system. The intent is to be compatible with the advanced avionics now being integrated into the aircraft and to be capable of supporting tri-Service force packages of up to 100 Aircraft.

Army

The Army has three primary CTCs where live simulation is performed: the NTC at Ft Irwin, CA; the Joint Readiness Training Center (JRTC) at Ft Polk, LA; and the CMTC at Hohenfels, Germany. The NTC and the CMTC are used to train battalion size heavy armor and mechanized units while the JRTC is used to train light infantry. Training is conducted continuously, though the capacity of the three centers limits unit commanders to one rotation per command. While some individual training takes place at the CTCs, the emphasis is on collective unit training. Strong points of training are tactics and techniques for employing weapons in support of unit missions and coordination of forces in space and time.

Improved instrumentation will allow more precise monitoring of each participants' actions and better measurement of unit performance with less instrumentation "overhead" cost than in the past. As virtual simulation becomes more sophisticated and more readily available at unit level, many of the activities now taught at the CTCs will be taught in virtual simulations such as the

CCTT. This will not eliminate the need for the CTCs, but it will allow the time spent there to be more focused on applying what has already been learned in the virtual environment to the constraints and uncertainties of the real world.

The Multiple Integrated Laser Engagement System (MILES) is used during live exercises for targeting and tracking casualties. MILES is being upgraded to include player identification, time tagged event storage, aspect angle discrimination, and improved accuracy. A Simulated Area Weapons Effects system is being developed for use with MILES to provide real-time simulation of indirect fire, mines, and chemical contamination. The Precision Range Integrated Maneuver Exercise system provides instrumentation for infantry and armor vehicles, opposition forces, pop-up targets, and dismounted infantry for realistic, controllable, MILES-based, and force-on-force live exercises.

Stand-Alone Single-System Simulation

Navy

The surface Navy lacks underway shipboard training systems. The Organic Component Systems Training Technology program was initiated to develop the technology for onboard, embedded training systems for combat systems, damage control, and hull, mechanical, and engineering training. Some of this technology will also be used for the BFTT program to meet future shipboard virtual combat training needs.

Navy/Marine Corps are upgrading several general weapon systems simulators: Indoor Simulated Marksmanship Trainer, Infantry Squad Trainer, LAV-25 Turret Trainer, Advanced Amphibious Assault Vehicle, Combined Arms Staff Trainer, and Moving Weapons 3-D Simulator. Work is planned to upgrade flight simulators for the E-2C, S-3, P-3, and T-34 series aviation trainers. Most of this work will be for avionics simulation, displays and visual systems. General aviation trainers being developed or improved include the Landing Signal Officer Trainer, Basic Electrical Trainers, Maintenance Procedures Trainers, the Avionics/Electronics System Advanced Trainer, and the Helmet-Mounted Mission Rehearsal Simulation System programs,

The Forward Deployable Aviation Simulator Technology program is designed to demonstrate critical technology components that will transition to the Deployable Aircraft Training System (DTATS) scheduled for 1996. Components include reconfigurable cockpits, threat simulations, helmet mounted displays, interactive crew coordination, and photo-based image generators. The purpose of the DTATS program is to provide carrier deployed aircrews with a simulator that will provide training in critical flight tasks and mission rehearsal. Currently, aircrews have no simulation capabilities once the ship leaves pierside.

Air Force

The Air Force is the biggest user of flight simulators of all the Services and also a major user of aircraft weapon systems simulators. It has ongoing or planned programs to upgrade simulators for B-1B, C-17, C-141, Special Operations Forces Aircrew Training System for aircrew and maintenance personnel, Joint STARS Flight Crew Training System, KC-135, F-15E, F-16, Improved Electronic Warfare Training Device, Low Altitude Navigation and Targeting Infrared System for Night Simulator and Part Task Trainer, Simulator for Electronic Combat Training, and On-Board Electronic Warfare Simulator.

Army

The Army has many ongoing and planned programs, ranging from aviation and artillery to tank and maintenance simulators. Included in the aviation simulators are upgrades to the UH-60 cockpit and emergency procedures trainer and the Future Aircrew Sustainment Trainer, the UH-1 Flight Simulator, and the OH-58D Crew Station Mission Equipment Trainer. The Air Ground Engagement System II (AGES II) incorporates MILES on the AH-64, OH-58D, UH-60, and CH-47, and includes HELLFIRE, rockets, and 30mm cannon simulation. Planned artillery simulation system upgrades include the Advanced Field Artillery System, which will include embedded training for operators and maintainers for the 155mm Howitzer. The main tank crew simulators are the GUARDFIST I and II systems. GUARDFIST I is a tank-appended training device that provides background scenes and fixed and moving targets. The system provides for offensive and defensive target engagements with simulated tank component malfunctions and audio and voice cues. GUARDFIST II trains forward observers in target identification and call for fire, and includes fixed and moving targets with realistic explosion effects. The Advanced Gunnery Training System will train precision and degraded gunnery skills for the M1A1, M1A2, M2/M3A3, and Armored Gun System gunners, commanders, and maintainers. The MK-19 grenade machine gun training system will train the skills associated with firing the MK-19 and will be operable with the instrumentation systems at the CTCs. The Precision Gunnery Training System will train TOW and DRAGON gunners.

Virtual Simulation

Navy

The BFTT links the systems of ships anchored at pierside through networks for multi-ship, multi-warfare team training. It supports fifteen different classes of surface ships and will eventually include undersea capability (Department of the Navy, 1993). The TCTS, a live simulation that can be linked to BFTT, provides simulated threat, sensor and weapons information to aircraft in flight and provides debriefing information for aircrews. The Navy is also participating in the MDT2, a Joint Service program that uses virtual simulation to support full Joint training in the air-ground environment. The first application of MDT2 was an evaluation of its ability to support training in close air support. Another application by the Navy will be to evaluate the MDT2 for conducting tactical training of aviation teams. The primary purpose of each of these programs is to evaluate and quantify the training effectiveness in the chosen application. Both MDT2 programs are supported by funding from the Services as well as OSD. The results will identify those tasks which can be trained using this form of simulation, the potential for increased use, and provide some indications of possible savings resulting from their adoption for training.

Air Force

The Air Force is performing a limited amount of work in virtual simulation. The Special Operations Forces Advanced Training System links aircraft training devices into a virtual environment and uses protocols to connect the devices for collective unit training. The Contingency Visualization and Planning Support program combines perspective scenes of photo imagery and terrain elevation and allows real-time fly-through in a simulator environment. This system will soon have the capability to link multiple sites. The Air Force participates in the MDT2 research program and in an internal program called MultiRAD (Multiship Research and Development) (Orlansky et al., 1994). MultiRAD links two F-15C cockpit simulators, an air weapons controller, two dome simulators, and two enemy cockpits.

Army

DoD has designated the Army as the lead Service for virtual simulation. The Army program manager for virtual simulation is responsible, among other things, for managing the Battlefield Distributed Simulation-Developmental program, which will develop capability definitions and identify technology development issues. The Army's Combined Arms Tactical Trainer (CATT) is the most ambitious virtual simulation program in DoD. Its goal is to provide a simulation wherein all the elements of the combined arms battlefield can simultaneously be represented and exercised. This will allow for the combining of all applications of combat power without regard for peacetime restrictions of environment, economics, or safety, and will also enable the conduct of interactive training at home between field exercises. Components of CATT include the Close Combat Tactical Trainer, the Aviation Arms Tactical Trainer, the Air Defense Combined Arms Tactical Trainer, the Fire Support Combined Arms Tactical Trainer, and the Engineer Combined Arms Tactical Trainer.

Constructive Simulation

As noted previously, there are literally hundreds of constructive simulations and they are used extensively by all the Services. This section does not attempt to survey them systematically, but merely highlights prominent programs and plans. The Aggregate Level Simulation Protocol, currently under development, will enable different constructive simulations (each focusing on a different aspect of the combat mission) to link up and share information; this development will benefit constructive simulations in all the Services.[15]

[15] Historically, constructive simulations have been run out of a single site, with a dedicated staff assigned to run the simulation. Better communication capabilities and an emphasis on taking the training to the customer are resulting in the ability to interconnect simulations running at remote sites. This shared information can be used within each of the simulations as required. Thus, the logistics support function being run in one simulation can affect the number of combat vehicles available for an upcoming battle which is being resolved in another simulation.

Navy

The major constructive simulation in the Navy is the Enhanced Naval Warfare Gaming System, which provides a real-time decision-making environment focusing on tactical decision-making, tactics development/evaluation, and operational planning/execution. The system also allows tactical commanders to plan, execute, and evaluate fleet operations, operation orders, and exercises.

Air Force

The Air Force has a large constructive simulation program. Air Combat Command sponsors *Blue Flag* to train air component commanders and their battle staffs in a realistic C3I environment. The model simulates such tasks as logistics; sortie launch, generation and recovery; battle damage assessment; and intelligence. There are four exercises per year with elements from all the Services participating.

The Warrior Preparation Center is an Air Force/Army simulation center that provides C3I training to commanders and their staffs. It runs eight to 10 exercises per year with each Service and NATO participating. The Air Ground Operations School uses theater level war scenarios to train individual skills at each of forty different duty positions (Department of the Air Force, 1993). Individual skills, from chief of staff level down to squadron officer level, are taught at the Air Force Wargaming Lab. Task force and Joint staff skills are taught at the Air Force Battle Staff Training School and the Warrior Preparation Center. The Air Warfare Simulation is currently used as an exercise driver for the air portion of Air Force and Joint battle staff training exercises. It is scheduled to be replaced in the mid to late 1990's by the National Air and Space Warfare Simulation model, which will have open architecture to support other Service simulations and the capability to connect with virtual and live systems.

Army

The Army has an active constructive simulation program and plans to upgrade and enlarge several of its systems. Janus includes most ground and air systems involved in offensive and defensive ground combat operations and can handle conflicts of up to Blue battalion versus Red regiment forces. Players make decisions based on continuous presentation of the battle on a map-like display and on-call status reports. The Corps Battle Simulation is a relatively low resolution system for training commanders and staff in command and control procedures. Its follow-on, the Brigade/Battalion Battle Simulation, can be played at the individual vehicle level and is used for training of brigade/battalion commanders and their staffs. The next generation constructive simulation, now under development, is Warfighters Simulation 2000. It will support training at the battalion through theater level. It is intended to be open architecture and will link to other Army and Service simulations.

CONCLUSIONS

This section summarizes the DoD experience with simulation, describes the need for more cost-effectiveness data, describes some key DoD initiatives, and estimates the potential for increased use of simulation.

DoD Experience with Simulation

DoD has extensive experience with simulation in all the Services and in many different areas of training. There is ample evidence that simulation has been cost-effective for a wide variety of applications. The demonstrated benefits of such uses of simulation are (1) increased skill proficiency, (2) increased readiness, (3) decreased accidents, (4) decreased combat casualties, (5) reductions in training time, (6) reductions in the costs of ammunition, and (7) reduced wear and tear on actual equipment. Evidence suggests that the next generation of simulations will improve training and increase savings, simultaneously providing the capability to develop doctrine and tactics, assess war-fighting situations, define operational requirements, and assist the acquisition process. To achieve the full potential of simulation, DoD must monitor and manage simulation programs in a number of different areas--to increase the visibility of resources, improve the focus of evaluations, ensure that Service investments are balanced and complementary, and increase coordination across Services and Defense agencies.

The Need for Cost-Effectiveness Data

Simulation has proved to be effective and efficient for training on a wide variety of tasks. The newest simulations offer opportunities for further cost savings, but these savings must be determined through careful analysis of the costs, effectiveness, and limitations of simulation in each application. Continuous and systematic feedback on the cost, effectiveness, and limitations of modeling and simulation technology is critical in developing successful strategic policies, plans, and investment strategies. Without such data, it is difficult to determine the appropriate level of investment of current and planned modeling and simulation. DMSO's *Modeling and Simulation Master Plan* (DMSO, 1995) makes this point as follows:

> The optimal use of M&S [modeling and simulation] across DoD will not occur unless the positive (and negative) impacts and cost-effectiveness of M&S are documented and communicated. DoD Components must educate potential user communities on the existing and expected benefits of M&S employment so that they may make informed investment decisions. This education may include a wide variety of means such as on-line information systems, seminars, live demonstrations, formal courses of instruction, etc. Where authorized and cost effective, DoD must aggressively pursue the two-way transfer of M&S technology among DoD Components, other government agencies, industry, and allied nations (p. 2-11).

Implementation of the Master Plan will increase interoperability of Service programs, eliminate duplication of effort, and ensure re-use of simulation software. DoD is developing and will execute a *Modeling and Simulation Investment Plan,* to focus DoD's investments on areas with the greatest potential benefit; the goal is to provide the military with the best possible training, using the most efficient and effective combination of training technologies.

DoD Initiatives

DoD is supporting several studies to determine the cost-effectiveness of advanced simulation technology. Examples are evaluations of CCTT "Quickstart," Force XXI, and MDT2; these programs will document cost-effectiveness of advanced simulation for integrated ground combat and close air support. Additional research will be needed to quantify the potential of simulation across other areas of training, such as tactical air, integrated naval-amphibious-ground assaults, mission rehearsal, and joint operations. The CCTT will be the first advanced simulation training program to systematically quantify the OPTEMPO trade-off during acquisition testing. DoD's goal is not simply to find lower-cost substitutes for field training exercises but to determine the *best mix* of simulation and live training to optimize readiness based on valid cost-effectiveness data.[16]

Potential for Increased Usage of Simulation

Live simulation plays a vital role in preparing our forces for combat. A case can be made for increasing the amount of live simulation in the interService and Joint arena. Increased cooperation among the Services in this area has potential to improve the Joint training readiness of the force.

Stand-alone single-system simulation is used heavily by the Services and is cost-effective in many applications. The area with the greatest potential payoff for more application is probably in combat aircrew training. With real aircraft, this type of training poses the greatest risk for loss of life and aircraft if mistakes are made. There is not adequate data to make a recommendation regarding the increased use of simulators in lieu of OPTEMPO flying hours per aircraft, steaming days per ship, or ground vehicle miles. In general, the authors believe that the Services should be permitted to make this tradeoff on the basis of their assessment of the impact of simulation on the requirement to maintain readiness.

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[16] To achieve this goal, DoD reports that it is taking a number of different actions (OUSD, 1995). These include (1) reinforcing oversight of training simulation programs to assure that they focus on areas with the greatest potential payoff; (2) extending efforts to evaluate the cost-effectiveness of training technology beyond the current generation of flight and maintenance simulators (e.g., to advanced virtual simulations such as CCTT, Synthetic Theater of War, and MDT2, and the use of simulation for Joint training); (3) improving ways to measure performance in Joint training exercises; (4) developing data bases and supporting systems to compile performance data from large-scale Service and Joint exercises; (5) developing cost-reporting systems that will identify, define, and make regularly available cost-effectiveness data on the use of modeling and simulation for training that is needed to support investment and policy decisions.

Virtual simulation has the potential to enable Joint and interService training in mission areas not being trained in sufficiently now (e.g., close air support). The technology permits coordinated training among the Services while individual Service elements remain at their home stations. This technology is new, though it appears to have great potential. Continued investment should be made in this area to develop, test, and refine the technologies to enable it to reach its full potential.

The level of investment in constructive simulation is relatively modest in comparison with the other types of simulation. This does not however decrease its importance, especially in the command staff and Joint training areas. The Joint Staff and the various Unified and Specified Commands place increasing importance on the use of constructive simulations in their training programs. The new Joint Training Analysis and Simulation Center for U.S. Atlantic Command and the Joint War Fighting Center of the Joint Staff are critical links in providing training to the staffs of the Commanders in Chiefs. The authors believe that continued investment in constructive simulation based training is essential to the Joint readiness of the Total Force.

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APPENDIX

ABBREVIATIONS AND ACRONMYS

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AGES	Air Ground Engagement System
ARPA	Advanced Research Projects Agency
BFTT	Battle Force Tactical Trainer
CATT	Combined Arms Tactical Trainer
CCTT	Close Combat Tactical Trainer
CMTC	Combat Maneuver Training Center
CTC	Combat Training Center
DMDC	Defense Manpower Data Center
DMSO	Defense Modeling and Simulation Office
DTATS	Deployable Aircraft Training System
IDA	Institute for Defense Analyses
JRTC	Joint Readiness Training Center
MDT2	Multi-service Distributed Training Testbed
MILES	Multiple Integrated Laser Engagement System
NTC	National Training Center
O&M	Operations & Maintenance
OPTEMPO	Operating Tempo
OSD	Office of the Secretary of Defense
OUSD	Office of the Under Secretary of Defense
OUSD (P&R)	Office of the Under Secretary of Defense for Personnel and Readiness
R&D	Research & Development
RDT&E	Research, Development, Test, & Evaluation
REFORGER	Return of Forces to Germany
SIMNET	Simulator Networking
TCTS	Tactical Combat Training System
USACOM	U.S. Atlantic Command